The Foundations of Dark Energy: Studying the Local Sample

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Type Ia supernovae (SNe) provide the most direct inference of Dark Energy, yet questions persist of how representative the local sample is of the distant one. They are also undergoing crises both of classification, because there are two, and paradigm, because single degenerate -- thermonuclear disruption of a white dwarf star slowly accreting material from a binary companion – is unsustainable in the face of observations. The only tenable mechanism for Ia's, as well as Ibc's and more than 90% of Type IIs, is double degenerate (DD): the process in which two white dwarfs, or degenerate cores of more massive stars within a common envelope, with total mass in excess of 1.4 solar, merge, via collision or evolution, to produce core collapse. This can affect Ia cosmology, and hence Dark Energy. Fortunately, SN 1987A is a Rosetta Stone for DD SNe: its bipolarity can explain the high velocity features and inverse relation between luminosity and polarization in Ia's, and together with its "Mystery Spot," gamma-ray bursts (GRBs). Because SN 1987A was DD and made a lateral GRB, we can conclude that DD does in fact, make long, soft GRBs (ℓGRBs). But because only short hard GRBs (sGRBs) occur in elliptical galaxies (EGs), where DD must be the predominant SN/core-collapse mechanism, then DD also produces sGRBs, and neutron star (NS)-NS mergers may not make GRBs as we know them, and/or be as common as previously thought, a severe disappointment to the hopes of Earth-based gravitational observatories for frequent, easily detectable events. We therefore propose to conduct a study of SNe and GRBs in the full light of the DD paradigm, using the vast amount of data available from SN 1987A and others. This study has the potential to: 1) fix the current systematic problems suspected in Ia cosmology, 2) learn enough about merger-induced SNe/GRBs to better understand them, and, in the process, 3) facilitate and constrain (the currently prohibitively difficult and poorly constrained) calculations of this process, and 4) assist gravitational observatories in their attempts to detect such relatively frequent events (the ***only*** such ones). We will attempt to accomplish this latter by preparing for, and making feasibility observations, using the largest Earth-based telescopes available, of the nearest recent Type Ia/c SNe (and SNe 1987A and 1986J as well), both now guaranteed to be core-collapse events, usually at 0 – 3 years of age, to determine the rates of spin and spinning down of their ~2 ms (~12 ms? in the case of 1986J), embedded, optical pulsar remnants. Finally, the study would assess the extremely unlikely, but grave threat that these events pose to our planet.

1. Scientific Background

1.1 Introduction

Type Ia supernovae (SNe Ia) have been used by at least two groups, all without any explicit foreknowledge of their progenitors, to argue that the expansion of the universe is accelerating, and hence for the existence of "Dark Energy," or a cosmological constant, Λ (see, e.g., Riess et al. 1998; Perlmutter et al. 1999). This has the appearance of convenience, as it helps several other lines of inquiry, including the scale size of the fluctuations of the surface of last scattering of the cosmic microwave background (CMB), and measurements of the clustering mass on large scales (see, e.g. Eisenstein et al. 2005), converge to a consistent set of parameters, generally $\Omega_m \sim 0.3$ and $\Omega_\Lambda \sim 0.7$. However, at present SNe Ia represent the only firm, direct evidence for the existence of Dark Energy (see, e.g., Conley et al. 2006). We argue here that Ia's are related to, and can be better understood by, the study of, 99% of other SNe and gamma-ray bursts (GRBs).

1.2 The Problems with Type Ia Supernovae

There are many serious problems in casting Ia's as single degenerate, i.e., total thermonuclear (TN) disruption of a white dwarf (WD) pushed to the Chandrasekhar mass (1.4 $M_\odot$) by gradual accretion of material from a binary companion. These include: (1 & 2) no SN-ejected or wind-advected H/He (Marietta et al. 2000; Lentz et al. 2002), (3) ubiquitous high velocity features (Mazzali et al. 2005), (4 & 5) SiII and continuum polarization (CP) both inversely proportional to luminosity (IPL – Fig. 1, and Wang et al. 2006; Middleditch 2006), (6) no radio Ia SNe, as would be expected for a SN within an accreting binary system (Panagia et al. 2006), (7) *four* Ia's within 26 years in the merging spiral/elliptical galaxies comprising NGC 1316 (Immler 2006), (8) >1.2 $M_\odot$ of ^{56}Ni in SN 2003fg (Howell et al. 2006), (9) cataclysmic variables are explosive, and thus the WD companion can *never* reach 1.4 $M_\odot$ this way (Scannapieco & Bildsten 2005), and (10) core-collapse (CC) SNe are needed to account for the abundance of Zinc (Kobayashi et al. 2006).

These problems, in addition to Ia's falling into at least two classes, have been admitted openly during the April 2007 SN conference at Santa Barbara (Siegfried 2007). Previously, at the SN 1987A: 20 Years After conference in Aspen, late on Wednesday afternoon, the question was asked: "Is there any way of avoiding double-degenerate for these [Type Ia SNe]?" Someone ventured an answer, but Nino Panagia reminded him that his suggestion had already been discredited. There was no other reply.[1] Filippenko, Janka, Kirshner, and Wheeler were all there. Also alarming is the recent evidence against the existence of Dark Matter (Nelson & Petrillo 2007), which puts Concordance Cosmology out in the cold, as 0.7 plus 0.03 is no longer close to unity.

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[1] Leonard (2007) has referred to earlier work (Livio 2000) which appeared to contra-indicate DD, but there is no reason why core-collapse *and* TN burning to ^{56}Ni should be mutually exclusive, given enough mass in excess of 1.4 $M_\odot$. DD Type IIs, such as SN 1987A (see Sections 1.4 and 2.1), manage to produce ^{56}Ni, albeit in smaller amounts, due to dilution of their TN fuel with at least He due to the merger process. Clearly, since Ia's are DD, the high Fermi energy of the electrons near the proto-neutron star does not extend sufficiently far outward to suppress burning to elements with equal numbers of neutrons and protons, such as ^{56}Ni -- the theoretical overkill (and now clearly wrong) explanation for the paltry amounts of ^{56}Ni produced by Type IIs. N. Panagia was also one of the editors of the book containing this reference (Livio 2001). Also, contrary to Leonard's statement that "... the detection of *any* amount of hydrogen would deal a death blow to the double-degenerate scenario" miniscule post-classification amounts of H (Hamuy 2003) are no problem with DD *collision*-induced merger to core-collapse.

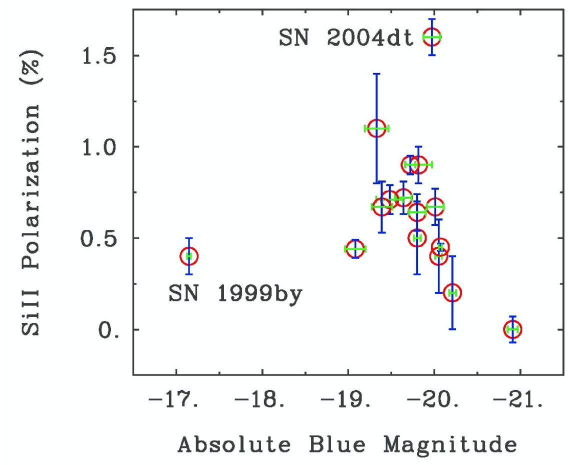

Fig. 1. After Wang et al. 2007, *Science*, 315, the inverse relation of SiII polarization in Type Ia supernovae vs luminosity, just one of the many good reasons why Ia's can not be single degenerate. Absolute magnitudes were calculated as 1.95278x Δm_{15} (B) - 22.335, except for SNe 1999by, 2004eo, and 2005cf, which had measured values.

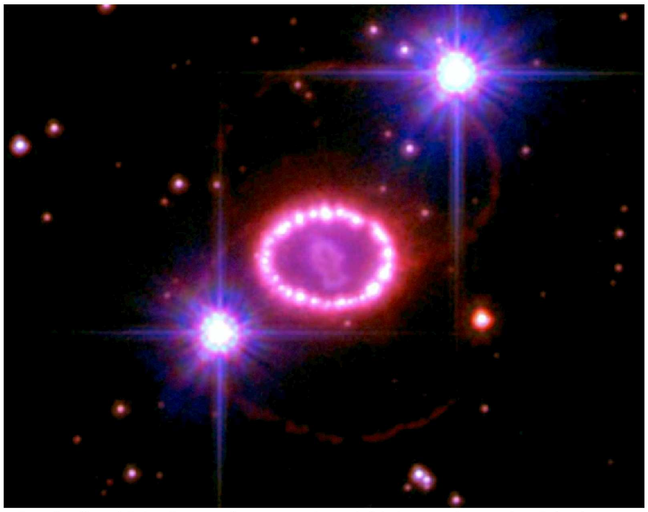

Fig. 2. SN 1987A as of December 2006, as viewed with the HST (NASA, P. Challis, & R. Kirshner, Harvard-Smithsonian Center for Astrophysics). The bipolarity of the explosion is suggestive of (electron) degenerate core-core merger-induced collapse ("Double Degenerate" – DD). The axis of the bipolarity corresponds to the "Mystery Spot" bearing of 194^o (the far-side [southern] minor axis of the equatorial ring has a bearing of 179^o).

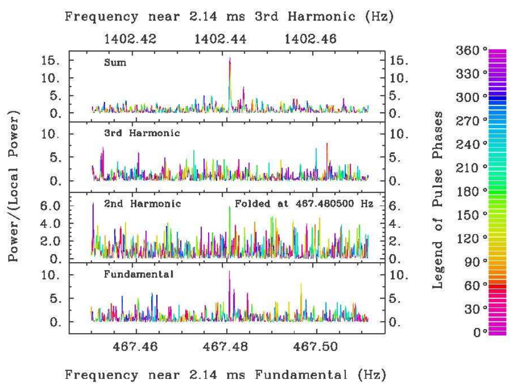

Fig. 3. (Lower three frames) The Fourier power spectra plotted for frequency regions near 467.4805 Hz and its first two higher harmonics from data taken with the Univ. of Tasmania Canopus 1-m Telescope during mid UT July 26, 1993. (Top frame) The sum spectrum of frequencies near the fundamental and 2nd harmonic. The peak in the sum spectrum near 1402.4417/3 = 467.48056 Hz is significant above the five sigma level (probability ~1:6,500,000). The second highest peak corresponds to the 1,000 s modulation seen in many other observations. The first 3 results from Tasmania confirmed the reality of the 2.14 ms optical pulsar in SN 1987A (get used to it, the probabilities in Middleditch et al. 2000, New Astronomy, 5, 243, aren't off 8 orders of magnitude).

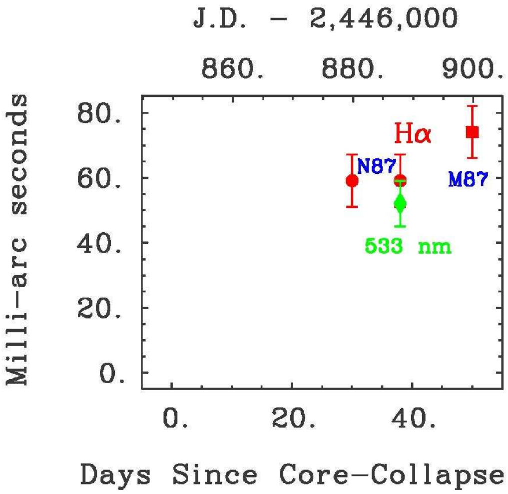

Fig. 4. Measurements of displacement of the "Mystery Spot" (MS) from SN 1987A, at Hα and 533 nm, vs time, from Nisenson et al. (N87), and Meikle et al. 1987, Nature, 329, 608 (M87).

1.3 The Double Degenerate Paradigm(s)

That SNe Ia, along with all others, except the rare iron photodissociation catastrophe events (FePdC) in massive stars, are due to DD -- the merger two stars, through collision as with CO WDs in globular clusters (GCs), or through evolution, as cores of a common envelope (CE) Wolf-Rayet binary system (WR – see DeMarco et al. 2003) -- has been hinted at a number of years ago, (Middleditch 2004,6 – hereafter M04 & M06). Up to 99% of *all* types of SNe are DD, allowing for helium (He – Type Ib's & IIb's) and hydrogen (H – Type IIs), or neither (Type Ia's and Ic's) in the CE, as differences in outer envelopes matter little to the merger DD process. In Ia's, as in all DD SNe, some 1.4 $M_\odot$ is lost to core-collapse (CC) in producing a neutron star (NS) remnant. *Unlike* any other SNe *except* Ic's, the remaining overlayer of C and O, intimately mixed by the merger process and undiluted by H or He, is ignited on broad fronts upon initiation of CC, and burns and/or detonates very efficiently.[2]

Because the WDs producing DD CC do not have strong magnetic fields (typically only several 100,000 Gauss), the NS remnant resulting from the merger will be only weakly magnetized (typically a few 10^9 G), but, because of conservation of the angular momentum of a merged, pre-CC WD with a 1.98 s rotation period (set by the branching of the Maclaurin and Jacoby solutions for the rotation), the resulting NS will be spinning at nearly 500 revolutions s^{-1}, consistent with the fastest pulsar in the non-core-collapsed (nCCd) GCs (2.10 ms), and the 2.14 ms signal from SN 1987A.

1.4 SN 1987A -- the Rosetta Stone

By now, the bipolarity of SN 1987A, the recent and well studied SN in the nearby Large Magellanic Cloud (LMC), is clear, as shown in Fig. 2 (NASA et al. 2006; Wang et al. 2002). A polar blowout feature (PBF – a possible and needed source of the "r-process" – see, e.g., Arnould et al. 2007) approaches at about 45 –55^o off our line of sight. It partially obscures an equatorial bulge/ball (EB), behind which a part of the opposite, receding PBF is visible. The PBFs and EB are approximately equally bright, in contrast to what the IPL polarizations imply for Ia's.

A binary merger of two electron degenerate stellar cores (DD -- in isolation these would be WDs) has been proposed for SN 1987A (Podsiadlowski & Joss 1989), and the triple ring structure has recently been calculated in this framework (Morris & Podsiadlowski 2007). Many other details of 87A, including the mixing (Fransson et al. 1989), the blue supergiant progenitor, the early polarization (Schwarz & Mundt 1987; Barrett 1988), and the 2.14 ms optical pulsations (Middleditch et al. 2000a,b – hereafter M00a,b) strongly support this hypothesis (see Fig. 3).[3] As a

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[2] This explains the high luminosity of Ia's above all other types of SNe (except the rare FePdC SNe), including the >1.2 $M_\odot$ of ^{56}Ni produced in SN 2003fg, without inventing "super-Chandrasekhar'" mass WDs (Howell et al. 2006). It also explains how SN 2006gy could have produced ~20$M_\odot$ of ^{56}Ni (see also Section 1.4.3), without resorting to episodic pair instability stars (Woosley et al. 2007), or dense clusters of massive stars (Portegies Zwart & van den Heuvel 2007).

[3] The Canopus 1-m Telescope of the U. of Tasmania had little response in the UV, but given the airmass of Hill and Watson's early (and confirming) observations, this *helped*! The HST/HSP 24.5 magnitude optical limit reported by Percival et al. (1995) is exaggerated too faint by a factor of 10, thus their actual limit is 22.0 at best, as can be easily verified by HSP count rates achieved on objects of known magnitude. In fact, HSP observations taken on 1992, June 2nd and 1993, March 6th did show 2.14 ms signals at magnitude 22.3 – 22.7, and the HSP team was informed of these by us, with no response, and we could only speculate the team could not deal with other than overwhelmingly significant signals. A limit of 24.5 *could* be achieved for a total count rate of 1/s, but the rate for SN 1987A was 100/s.

DD Type II SN, 1987A differs from the Ia DD scenario only in that it had H and He left in a CE, possibly resulting from a merger of two stars of only moderate mass (~8 $M_\odot$ each), producing the neutrinos heralding the birth of an NS (Bionta et al. 1987; Hirata et al. 1987).

So far, SN 1986J is the *only* known recent, nearby exception to the DD paradigm -- a CC of a massive star resulting from FePdC (thought to produce NSs, or black holes for the very rare progenitors with mass >75 $M_\odot$[4]– because it's luminosity at 15 GHz exceeds that of the Crab nebula by a factor of 200 (Bietenholz et al. 2004), and thus the compact remnant is a *strongly* magnetized NS/pulsar.[5] On the other hand, SN 1987A is likely to have been a DD SN, not just because of its bipolar explosion and side effects such as early polarization, but because of the blue supergiant (BSG) progenitor (Sanduleak 1969), and the details of the three inner rings, including the slow, 10 km s^{-1} expansion of the equatorial ring (ER -- Burrows at al. 1995), characteristic of H gas at 10^4 K, lost from a common envelope system through one or both outer, mass-axis Lagrangean points.

The most remarkable feature[6] of SN 1987A was the "mystery spot" (MS), with a thermal energy of 10^{49} ergs, even 50 days *after* the CC event (Meikle et al. 1987; Nisenson et al. 1987; hereafter M87 & N87), and separated from the SN photosphere "proper" by 0.059 arc s *along the axis of its DD merger* toward the Earth, 45 – 55^o off our line of sight (see Figures 4 and 5). The approaching polar beam/jet produced by SN 1987A, which collided with what is thought to be previous polar ejecta (PE) ~20 light-days (ℓt-d) distant from the SN along this axis, is *generic* to the DD process (M04). Through its interaction with the overlaying CE and/or PE, it produces the wide variation in GRB/X-ray flash properties observed from DD SNe of sufficiently low inclination to the line of sight (see Sections 1.4.2 and 2.1 below).

Unfortunately, this error is still propagating in the literature as, e.g., in Manchester (2007), in spite of our having corrected him at the time of the corresponding oral presentation a few months prior to the deadline for the proceedings. Manchester's last optical observation used about *half* of two nights on the AAT, consisting of two 100 min observations within each night during 1994, early Dec. (Manchester & Peterson 1996). Having spent nearly 19 hours observing SN 1987A with the CTIO 4-m during 1993, Dec. 28 – 30, which established a limiting magnitude of 24.0 in the combined V, R, and I bands (a gold secondary -- about 2/3rds of the total wide open band count rate), and in which actual candidate signals were observed on each of the three nights at mag. 24.44 – 24.78, the best estimate for his limiting V magnitude is likely at least a magnitude lower than his quote of 24.6. With no AAT observations in the interval from 1992, Feb., and 1993 Sep., when the 2.14 ms signal was seen most consistently (an AAT observation in 1993, Sep., was clouded out), and only 160 minutes of HSP observations in the *years* before the HST fix, both efforts were effectively inadequate for one reason or another. Manchester's assertion of no detection of the 2.14 ms signal since 1996 is only trivially true because SN 1987A has not been observed since then, except for a broadband limit of 22.6 from imaging (Graves et al. 2005). Another team had a night in common with us *during this interval* at the ESO 3.6-m, visited us at LCO on the afternoon prior to the night, promised to share their data, but ultimately wrote over it, without so much as writing down a single Fourier amplitude!

[4] Since FePdC SNe can produce many $M_\odot$ of ^{56}Ni, and thus lift a lot of material out of core collapse, we do not consider the ~40 $M_\odot$ of ejecta in W1 to require "millisecond magnetars" as remnants (see, e.g., Vink & Kuiper 2006).

[5] The origin of magnetic fields in NSs is still poorly understood, though it is believed that TN combustion in the massive progenitor to an Fe core is related. As a corollary, we note that models of SNe to date have not taken DD into account, and *certainly* have not been calibrated to an Fe PdC SN, such as 1986J.

[6] Not counting, for the moment, the 2.14 ms pulsed optical remnant, which also revealed a ~1,000 s precession (M00a,b). Since a prototypical, faint, dim, thermal neutron star remnant (DTN) has been discovered in Cas A (Tananbaum et al. 1999), representing what PSR 1987A will look like after another 300 years, and other pulsars have since been observed to precess (Stairs et al. 2000), this candidate is no longer controversial.

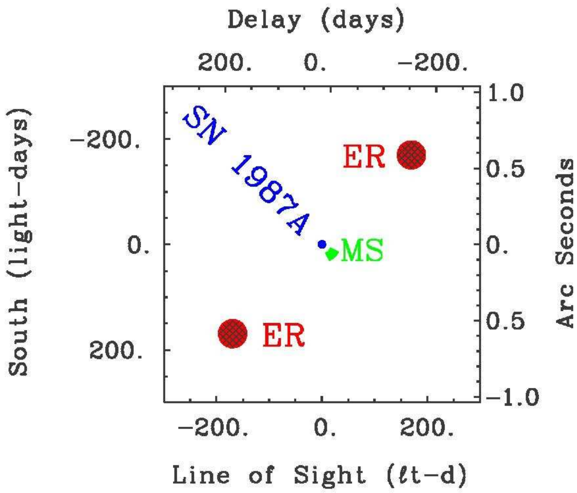

Fig. 5. The geometry of the "Mystery Spot" (MS) relative to SN 1987A and the equatorial ring (ER -- shown in cross-section).

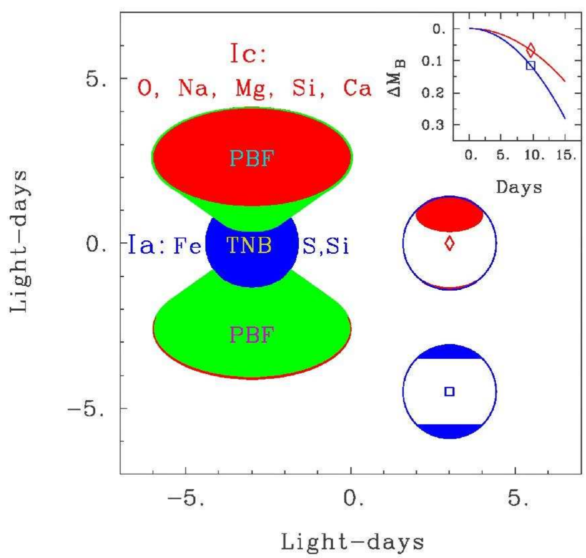

Fig. 6. The geometry for Type Ia SNe, as viewed 30° off the merger equator. The thermonuclear ball (TNB), whose luminosity is dominated by the decay of ^{56}Ni, is shown in blue, while the polar blowout features (PBFs), each with a half angle of 45°, are sketched as cones with green surfaces and red ends on the left. Systematics can occur because there is less material to be ejected in Ia PBFs than in those of Type II SNe such as 1987A, and as a consequence the Ia PBFs are ejected with a higher velocity, possibly exposing the PBF footprint on the TNB, shown for co-inclination (co-i) 30° in red/blue on the right (upper/lower), during the interval when Δm_{15} is measured (inset in uppermost right -- the curves are for an intrinsic Δm_{15} of 0.5 mag). If TNBs start out as toroids, as seems likely, the difference between the red and blue curves could easily be twice as large, particularly for low co-i's, accounting for the full effect in Ia cosmology. Also, as drawn at upper left, Ia's viewed pole-on are Ic's, given sufficient matter in the overlayer. Otherwise, it would just beg the question of what Ia's viewed from the poles *would* look like.

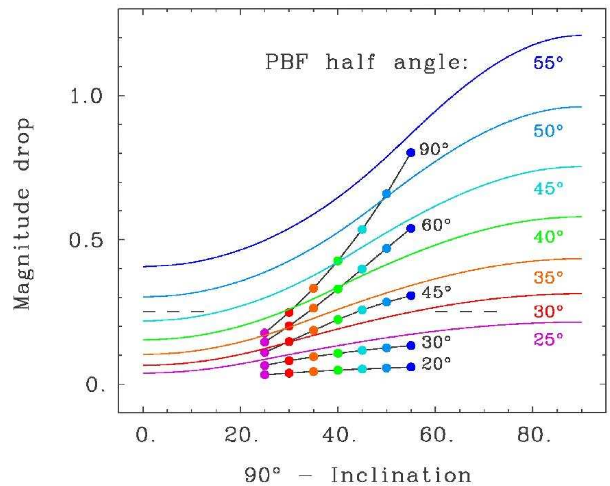

Fig. 7. The maximum drop in magnitude from exposure of the PBF footprint(s) to an observer are plotted as a function of co-inclination for PBF half angles of 25-55°, assuming no contribution to the change in luminosity from the PBFs themselves. The curves with disks represent the *changes* in the drops in magnitude between the co-i's labeled at their right hand ends, and the drops at 0° co-i, and the points are plotted on the abscissa at co-i's corresponding to their PBF half angles. The dashed lines represent the effect needed to spuriously produce $\Omega_\Lambda = 0.7$.

1.4.1 The Implications for Ia's

Ia's produce NS remnants, but differ from other DD SNe in that they almost never have polar ejecta for a beam/jet to hit, and frequently do not have much CE, thus their beaming factors are usually only modest (see Section 2.1). Although the luminosity of a typical Ia will be dominated by the EB/TN ball (TNB) due to the high concentration of ^{56}Ni within it, its PBFs will have even higher velocities than those of SN 1987A, due to their less massive CEs.[7] If we accept the validity of the calculations of TNBs (Pinto & Eastman 2001), that show these should obey the width-luminosity (WL) relation, then a subclass of Ia's viewed off their merger equators will exist that do *not* if their PBFs expose a fraction of their TNBs during the interval when Δm_{15} is measured, as seems likely.[8]

Occam's razor alone would argue that Ic's are Ia's viewed from one of their merger poles, where the bright signature of ^{56}Ni and the nuclear ash consisting of S, Si, Fe, is hidden from view because of the bipolar nature of the DD CC explosion, given sufficient mass in the overlayer. Assuming they weren't would beg the question of what Ia's viewed from their poles *would* actually look like, and, given that DD already produces GRBs (see further below), there is *no need* for *another* mechanism for stars less compact than NSs. The extreme velocities[9] which led to inventions of "hypernovae," "supranovae," "collapsars," and other exotica are possibly due only to the direct, early view of the PBFs, and a light (but non-absent) load of material in the overlayer. Their association with actively star-forming galaxies (ASFGs) can be explained by the formation of binaries. As might be expected, Ic's are also nearly absent from ellipticals, likely due to insufficient material in the overlayer to shroud the TN products, consistent with the "leaner" Ia's typical of these non-ASFGs noticed by everyone (Hamuy et al. 2000; Sullivan et al. 2006;Wang et al. 2006a). Since no SNe have been found in some GRBs with optical afterglows (Gal-Yam et al. 2006; Fynbo et al. 2006; Della Valle et al. 2006; Gehrels et al. 2006), Ia DD CC can be very lean indeed, so lean, in fact, as to be non-bolometric even in the WL sense.

Intrinsically very low luminosity Ia's, which fall 1 – 2 whole magnitudes (mag)[10] below the WL relation, can be excluded from distant samples because of an easily detected TiII shelf from 400 – 450 nm (possibly a hallmark of cooler burning which may be characteristic of intrinsically faint Ia's). However, unless the shelf itself is actually *only* a hallmark of inclination (which seems unlikely, but if so, would still have to be calibrated), higher luminosity Ia's viewed off the merger equator will still be significantly below the WL relation, but will *not* have the TiII shelf, and thus will be accepted into the distant, but likely not the local sample. We propose to correct for this effect, which need only average 0.25 mag to spuriously produce the entire Dark Energy effect in Ia cosmology. Figures 6 and 7 show how this process can spuriously produce half of $\Omega_\Lambda = 0.7$ for a 30^o co-inclination (co-i) if the local Ia sample was selected for an equatorial view.

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[7] For DD SNe, the elements are mixed by the merger process, thus there is no amplification of velocity by inner layers of higher atomic number (Z) colliding with those of outer layers with lower Z. Thus less CE mass *does* result in higher ejection velocities, even if the CE contains only C and O.

[8] Unless, by some miracle, averaging over the bipolar geometry corrects itself, which must be considered highly unlikely, in view of the inverse relation between polarization and luminosity (M06).

[9] There is good evidence that SN 1987A ejected particles with velocities as high as 0.92 c (see Section 2.1).

[10] One magnitude is a factor of ~2.5. There are exactly five magnitudes in a factor of 100, the amount by which a source would dim if it were ten times more distant.

1.4.2 The Gamma-Ray Burst Connection

If we had taken the H and He out of the envelope of the progenitor of SN 1987A, Sk -69^{o}202, the beam/jet produced by its DD CC process which, in turn, produced the MS, would likely be indistinguishable from (and indeed *would* be) a full-up GRB. This realization, together with the observation that no soft, long-duration GRBs (ℓGRBs) have been found in elliptical galaxies, together with the further realization that the DD process *must* dominate (as always, through binary-binary collisions) by a large factor, the NS-NS mergers in these populations, even when requiring enough WD-WD merged mass to produce CC, leads to the *inescapable* conclusion that the DD process produces short, hard GRBs (sGRBs) prior to their passage through the CE and/or PE, the means by which they would otherwise become ℓGRBs. This is an amazing fact, as the fraction of sGRBs with durations shorter than 120 ms is well above 10% -- way too large to be all soft gamma repeaters (SGRs)[11] or NS-NS mergers – and the light travel time across the Earth's 12,756 km diameter, about the size of a WD, is still 42 ms. Thus, given that the sGRBs in ellipticals are due to nearly naked mergers of CO-CO WDs, the pre-CE/PE photon spectrum of ℓGRBs is *known*! This also explains why sGRBs are offset from the centers of their elliptical host galaxies, because they mostly result from WD-WD mergers in the ellipticals' GCs (see, e.g., Gehrels et al. 2005).

In addition, of the *three* different classes of GRBs, ℓGRBs, sGRBs, and the intermediate time, softest GRBs (iGRBs -- see Fig. 8), as recently classified by Horvath et al. (2006), most sGRBs occur from DD WD-WD merger without CEs or PE, ℓGRBs pass through at least the PE (necessary for 0.5^o deviations to produce 100s of s of delay), and usually the CE (which, in addition to the PE, can also soften it), while iGRBs pass through red supergiant (RSG) CEs, but little or no PE, possibly the result of a merger of two stars with very unequal masses, the possible cause of SN 1993J, which had an RSG progenitor (Podsiadlowski et al. 1993).[12] These could provide more CE material than the totals of CE and PE for mergers of stars with more nearly equal masses, possibly the blue supergiant progenitor of 1987A, Sk -69^{o}202, and thus generate bursts that are sometimes softer even than ℓGRBs (Fig.8). They easily provide more emergence delay (T_{90}) than sGRBs, because of the beam's/jet's passage through an RSG envelope, consistent with the ~10 s limit for T_{90} and its tradeoff with spectral hardness (H_{32}) for the iGRBs plotted in Fig. 8. This is still obviously much less delay than the 100s of s allowed by the much more distant (~20 light days) PEs of the ℓGRBs associated with mergers of stars with more nearly equal masses.[13] Like ℓGRBs, the pre-CE/PE photon spectrum of iGRBs is also known.

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[11] SGRs are NSs with very strong magnetic fields, $10^{14\text{-}16}$ G, the likely source of their bursts, and many are anomalous X-ray pulsars (AXPs) with rotation periods of ~6 s. About 5% of sGRBs are thought to be due to SGR events.

[12] At 1.6 and 1.0% (Trammell et al. 1993) the early polarization of SN 1993J was *twice* that of the 0.9 and 0.4% observed from SN 1987A (Schwarz & Mundt 1987; Barrett 1988), consistent with even *more* axiality than that of 87A.

[13] A one degree offset of a beam over the 20 or so light days distant PE of SN 1987A would delay the arrival of the non-prompt part of the GRB by about three minutes. The fluence of *both* the non-prompt and prompt parts of such off-axis ℓGRBs are suppressed, the first by scattering in the PE, the second by being off axis by the time it emerges from the CE, frequently leaving both roughly equally attenuated. This scenario also explains why the two ("precursor" and "delayed") have similar temporal structure (Naker & Piran 2002). Negligible spectral lag for late (~10 – 100 s) emission from "spikelike" bursts (Norris & Bonnell 2006) can be explained in terms of small angle scattering off the PE, without invoking extremely relativistic Γ's.

1.4.3 The Millisecond Pulsar Connection

There are many other conundrums of SNe and GRBs that the DD paradigm explains with *ease*, and part of the purpose of the requested funding is to explore them in greater detail. DD mergers of CO WDs explain the millisecond pulsars (MSPs) in Population II, and in particular, the large overabundance of MSPs discovered in the nCCd GCs such as 47 Tuc, over the last 20 years (Lyne et al. 1987; Chen et al. 1993).[14] In this picture, the MSPs with periods shorter than 2 ms are born that fast, and later recycled via accretion from a companion left over from what was most likely a binary-binary collision, a validation of Ghosh and Lamb (1979) without requiring field decay at any time. Thus 2 ms pulsars are injected into the MSP population (Fig. 9). Per above, DD explains the small amount of ^{56}Ni produced by Type IIs and Ib's, because their C and O layers[15] have been diluted by at least He by the mixing involved in the merger process. It also predicts that FePdC SNe, excluding those very rare, sufficiently massive ones that go on to produce black holes, will produce *much* more than the usual 0.06 – 0.12 $M_\odot$ of ^{56}Ni typical of Type II and Ib SNe, and will be brighter as a consequence of this, in addition to the energy input from the strongly magnetized NS remnants that we think these produce.

The DD CC process manages to produce what some astronomers have described as “hypernovae,” “supranovae,” and “collapsars,” and others as “MS(s)” and “GRB afterglows”. Calculating this is presently too ambitious (e.g., Fryer & Diehl 2007), because so little is known about it. It is by far the most frequent energetic event in the universe, occurring at the SN rate of one per second, and we will spend a good part of this half century figuring it out. With Dark Energy in need of further verification through SN studies, and LIGO currently running at design sensitivity, it's time to start.

1.4.4 The Gravitational Radiation Connection

That the vast bulk of sGRBs in ellipticals are due to DD CC and, to a much lesser degree, SGRs, is also a cold, hard fact for LIGO and other Earth-based gravitational observatories, as they can almost never assume that these are the result of the more (or what we think should be more) easily detectable NS-NS mergers. Thus for the Earth-based gravitational observatories, the DD SN process is almost always the *only* game in town. However, the short duration of such bursts is also a very hopeful fact, in as much as it could be the signature of a very violent final settling into the spinning NS configuration, which, in and of itself could produce detectable gravitational radiation out to a distance of 10 Megaparsecs (Mpc – 3,260,0000 light years),[16] enabling sensitive searches for chirps of increasing/decreasing spin frequency preceding/following the CC events.

1.4.5 Assessing the Danger

An FePdC SN of a massive star might be predictable enough so that Earth would be warned of the event. A DD SN, on the other hand, would give little or no warning. There is a slight advantage to belonging to a galaxy with high metallicity, as the CE and PE will be more opaque to gamma-rays because of such content. However, the GC, M4, is only 2 kiloparsecs away (kpc – 3,260 light years,

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[14] Recycled pulsars weighing 1.7 $M_\odot$ in the CCd GC, Ter 5 (Ransom et al. 2005), have removed high accretion rate from contention as a alternative mechanism to produce the MSPs in the nCCd GCs.

[15] Merged massive stars with H and He, progenitors of Type II SNe, can have a few $M_\odot$ of C and O!

[16] Dropping 0.5 $M_\odot 10^6$ cm in a gravitational field of 10^{14} cm s^{-2}, which can be considered as a radian of orbital motion in a system spinning at 500 revolutions/s, would take 2 ms/(2π) = 300 ms,and produce a strain parameter, h, of 5×10^{-21} at 10 Mpc. The final settling of the NS is an unknown, but, as this shows, distantly detectable GR events from DD CC can not yet be ruled out.

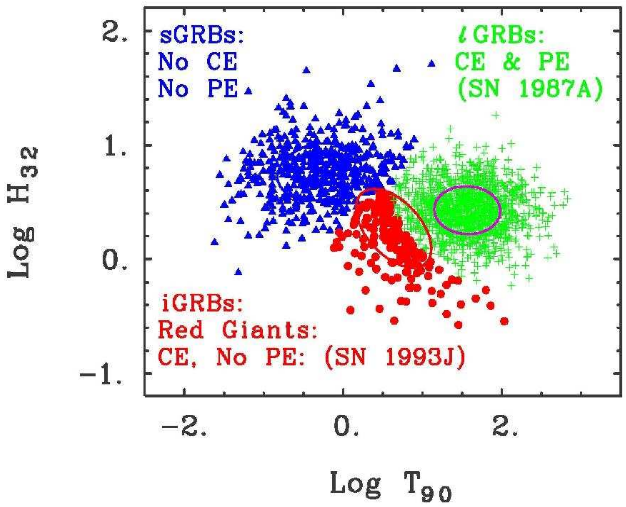

Fig. 8. After Horvath et al. 2006, A&A, 447, 23, the GRBs from the BATSE catalog (Meegan, et al. 2001, http://gammaray/msfc,nasa.gov/batse/grb/catalog/) are scattered in duration (T_{90})-hardness (H_{32}) space. The new third region (red) may be characteristic of merger-induced core-collapse within red *supergiants*.

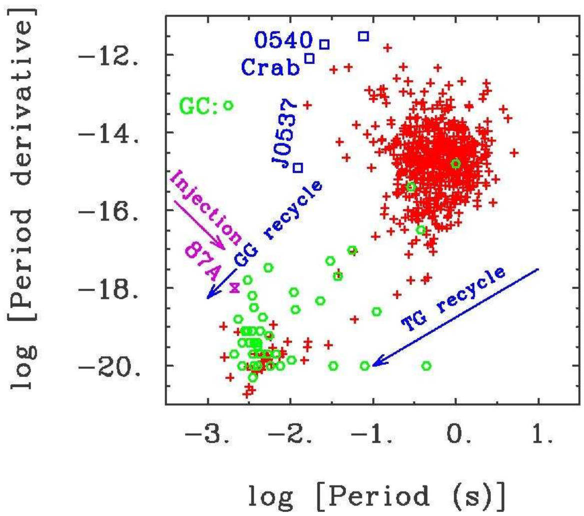

Fig. 9. About 700 pulsars scattered in the P-Pdot plane, some in globular clusters (green circles), most not (red +'s). Injection of a population of 2 ms pulsars occurs near the 87A point (magenta hourglass), most of these radio quiet (as with the Cas A X-ray point source). From there, most move a little right and down quickly due to gravitational radiation, where some are recycled, by accretion from merger-leftover companions, to periods shorter than 2 ms (gigaGauss [GG] recycle), moving to the left (& possibly also downward). Teragauss (TG) pulsars are recycled from the main group down and to the left, but generally not very far (in frequency) because of their high magnetic fields.

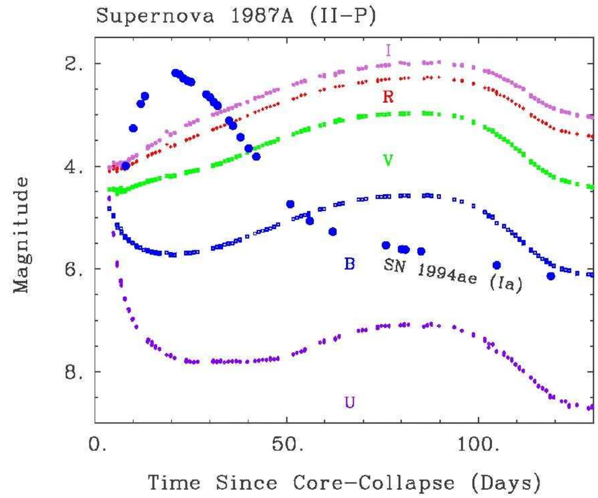

Fig. 10. The early light curve (luminosity history) of SN 1987A from CTIO (Hamuy & Suntzeff 1990, AJ, 99, 1146) in the five bands, U, B, V, R, and I, for the first 130 days following core-collapse, and the B light curve from the Type Ia SN 1994ae (blue disks -- from Riess et al. 1999, AJ, 117, 707), offset by -11 mag. The spike near day 20 in B, R, & I light from SN 1987A corresponds to about 10^{40} ergs/s (see Fig. 11).

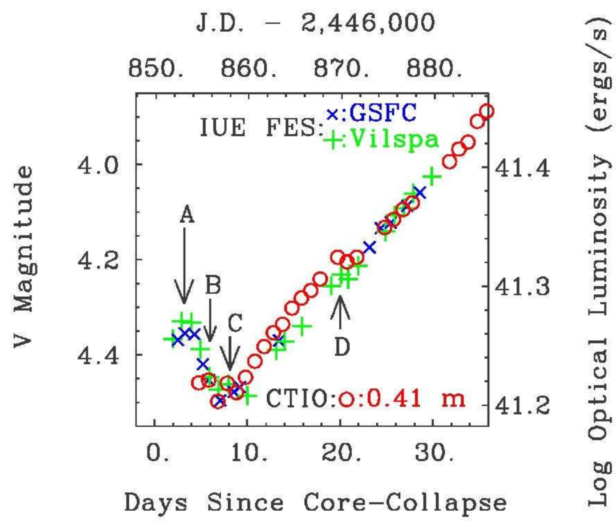

Fig. 11. After Hamuy & Suntzeff 1990, AJ, 99, 1146, and Wamsteker et al.1987, A&A, 177 L21 (and Sonneborne & Kirshner at GSFC), the very early luminosity history of SN 1987A as observed with the CTIO 0.41-m and the Fine Error Sensor of IUE. Various stages of beam/jet breakout and interaction with polar ejecta are labeled: A) breakout of luminous jet, B) the jet cooling or losing the ability to cool, C) the UV Flash hits the polar ejecta, D) particles penetrating polar ejecta producing light. The flux level near day 20 corresponds to 5.8 magnitudes above the day 7.0 minimum, the *same* as that measured for the MS in Hα at days 30, 38, and 50.

and NGC 6397 is not much farther), is very non-centrally condensed, and thus had to have merged two WDs in order to make its 11 ms pulsar, J1623-2631, producing a GRB in the process, possibly with no CE or PE to soften the blow (but without much CE would also probably be not very highly collimated). Of course, any pulsar resulting from a DD CC which had Earth in its sites would probably not be detectable because of its orientation. An apparent GRB fluence of 10^{54} ergs from M4 (lasting a few s) would deposit the equivalent of 3 *days* of sunlight, or about 10^5 times the solar flux for 3.4 s. Imagine the *entire* sky as bright as the sun. This would be unpleasant. There is also danger from SNe even those not aimed at Earth, for which Fe^{60} is a marker (Fields 2007). Is there a marker specific to the DD beam/jet? Further detailed studies of SNe and GRBs in the light of the new paradigm should lead to a more accurate assessment of the danger.

2. Experimental Approach

2.1 Beams, Jets, GRBs and Systematics in SNe

Sometimes it's hard to see the forest for the trees. This is certainly true for SN 1987A, for which there is a lot of very detailed data (the trees) from which we hope to determine the physics of DD CC (the forest). SN 1987A was a Type II-P SN, which means that it rose to an early plateau before curving over to the more typical ^{56}Ni decay slope, making this "bump" wider than it would be otherwise (see Fig. 10). It also had a jet/beam which impacted PE, producing the MS which was observed, via speckle interferometry, to be separated from it by about 0.059 arc s at 30, 38, and 50 days after CC, by two independent groups (M87; N87}, at a level near 7% of the stellar light at Hα (656.2 nm) corresponding to a total energy content of about 10^{49} ergs, with 3% of this eventually radiated in the optical. The MS direction coincides with the bipolar angle of 194 degrees visible in Fig. 2 (the minor axis of the ER is nearly due south, at 179 degrees). The geometry is such that it takes light only about *eight* extra days to hit it and continue on to be observed from the Earth (Burrows et al. 1995). In this interpretation, the first part of the linear rise in luminosity following the minimum, is due to (indeed *is*) the MS itself, the differences in the early parts of II-P "humps" being due to inclination and distance/structure to/in the PE.

Very early measurements of SN 1987A can be interpreted in the light of the beam/jet which had to exist and have *some* luminosity in the days prior to colliding with the nearest PE. Evidence for this sequence of events can been seen in a plot of data from the International Ultraviolet Explorer (IUE) Fine Error Sensor (FES) and CTIO as shown[17] in Fig. 11. There is a drop from the initial flash to below mag 4.35 before recovering by day 3.0, which can be interpreted as the breakout of the faster, hotter, central part of the beam/jet from its more outer, cooler, and roughly cylindrical layers. This declines to a minimum near mag 4.48 around day 7.0, interpretable as free-free cooling of the optically thin beam/jet, when the beam optical luminosity can be estimated to be 1.6×10^{41} ergs s^{-1}. It then shows a slight hump to day 8.0, *the same delay predicted from the MS geometry*, interpretable as the enhanced part of the beam's UV Flash scattering in the PE to produce about 2×10^{39} ergs s^{-1} for a day or so. The level drops by day 9.0, *consistent with a faithful echo of the UV flash* (the cross sections for the UV are such that no real penetration into the PE occurs). Because of this we know that the collimation factor (CF) for the enhanced part of the UV flash exceeds 10^4, and this, together with the 10^{49} ergs of the MS, confirms the energetics of a lateral GRB for SN 1987A. At day 10.0, the flux jumps up as the particles of the beam/jet begin hitting the PE, with the fastest particles traveling at 0.92 c. The abrupt rise also indicates a CF $>10^4$

[17] The CTIO V band center occurs at 550 nm as opposed to 510 nm for the FES.

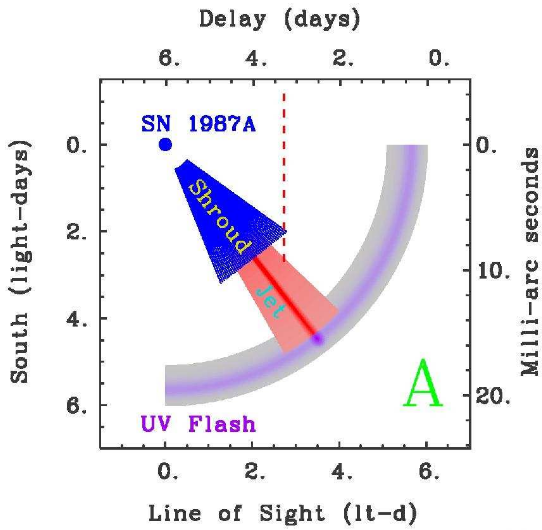

Fig. 12. The geometry of the 87A glowing beam/jet (BJ), initially opaque shroud, and UV Flash (which has an enhanced beam of its own in the jet direction (here 52°, down and to the right). The center of the emerging jet produces the rising luminosity shown at point 'A' in Fig. 11 at day 3.3 (read on the upper, delay scale). The maximum velocity of the jet is 0.92 c, that of the shroud, 0.55 c. Because of the short time response of the luminosity shown in Fig. 11, the full angular width of the jet has been set to 1.04°.

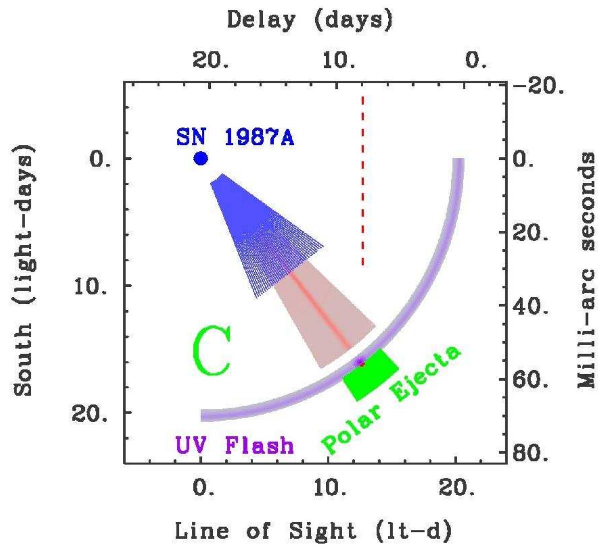

Fig. 13. The intense beam of the UV Flash scatters and reprocesses off the polar ejecta, producing the jump in luminosity at day 8 (top scale for the tiny red disk in the PE and 'C' in Fig. 11 – some 2×10^{39} ergs/s for a day). A polar ejecta density of 10^7 cm^{-3} would predict that the UV Flash does not penetrate it deeply, and this is confirmed by the dropoff of luminosity near day 9 in Fig. 11. The red disk corresponds to the highly collimated (~1°) intense beam of the UV Flash, and can not be much larger all because of the fast rise/drop in luminosity before/after day 8 in Fig. 11.

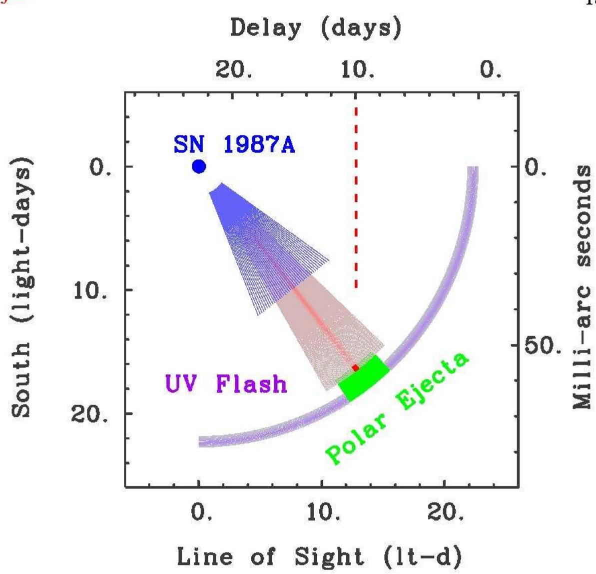

Fig. 14. The intense center (~1°) of the jet begins to produce light (red) as it penetrates into the polar ejecta (green), producing the jump in luminosity at day 10 (again, top scale for the red spot in this figure), visible in Fig. 11 for the same time. The penetration may continue because the cross sections for this process are orders of magnitude smaller than for the UV Flash. The 0.059″ offset of the spot corresponds (loosely) to measurement of the "Mystery Spot" shown in Figs. 4, and 5.

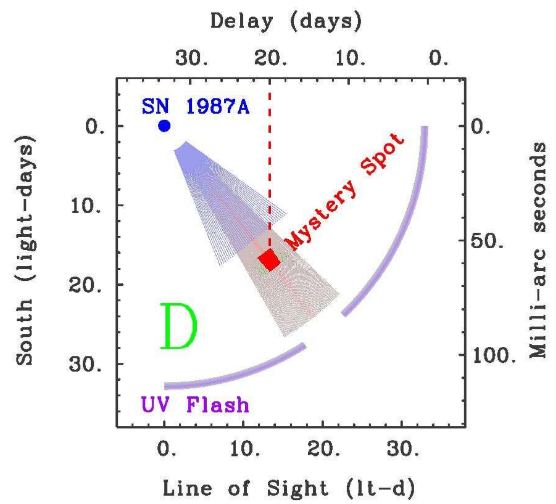

Fig. 15. Particles in the jet continue to impact the polar ejecta (green), continuing the ramp in luminosity visible in Fig. 11 near day 20 (top scale for the red strip in *this* figure [15]). By this time the rise from the 87A photosphere proper begins to contribute to the overall luminosity. Thus the MS luminosity can amount to no more than ~5×10^{40} ergs/s, or magnitude 5.8 (the same magnitude measured for Hα at days 30, 38, and 50 – see Fig. 11), about 23% of the total optical flux of 2.1×10^{41} ergs/s at day 20. A lifetime of 6×10^6 s yields the MS total optical output of 3×10^{47} ergs. A luminosity decrement of unknown origin appears in Fig. 11 just after this time.

for the particles. Figures 12 –15 show the development stages of the SN 1987A beam/jet, and their impact on the PE, indicated by its early luminosity history.

A decrement near day 20 is visible in both bands, but also appears as a spike of ~10^{39} ergs s^{-1} in the B, R, and I CTIO bands (Fig. 9). The CTIO point just before the decrement, a rough maximum for the MS luminosity, corresponds to an excess above the minimum (near day 7.0) of 5×10^{40} ergs s^{-1}, about 23% of the total optical flux of 2.1×10^{41} ergs s^{-1}, or 5.8 magnitudes, the *same* as measured for the MS in Hα at days 30, 38, and 50, thus the MS appears to have been self-limited in luminosity over a month or more. A lifetime of 6×10^{6} s at 5×10^{40} ergs s^{-1} yields the total optical output of 3×10^{47} ergs.

Thus a vast amount of detailed photometric data for SN 1987A is ripe for modeling under this paradigm. Middleditch has experience with novel photometric systems (Middleditch & Cordova 1982), and the analysis program is still lying around. We hope to learn how much its beam/jet has been modified by passing through the CE, and thus determine the initial *particle* content for the vast bulk of GRBs, *the last remaining piece of the GRB beam/jet puzzle*.[18] Other constraints on the beam/jet include X-ray upper limits, and UV, optical, and IR spectra. Many have invoked magnetic fields to explain breaks in the spectra of GRBs (see, e.g., Meszaros 2006). This may or may not be an unnecessary complication (see, e.g., Gonzalez et al. 2003), as magnetic interaction is over after a fraction of a ms for the weakly-magnetized, 2 ms pulsars formed. However, direct collisions of 0.92 c protons will leave electrons with relativistic Lorentz factors of 12, and for sufficiently low densities (the number density of the ER is about 10^4 cm^{-3}, scaling homologously inward to the PE would raise this only to 10^7), synchrotron radiation losses with ambient magnetic fields may dominate free-free losses (Cen 1999). Middleditch and a student will model the existing data in detail, and this effort should be mostly finished within a year.

2.2 Observational Effort

Fortunately, DD CC events are likely to be generic, with most producing MSPs with spin periods near 2 ms, which, if SN 1987A is any guide, will be optical pulsars for at least a few years. Knowing their spin periods more exactly, even three years after the event, will almost certainly help us detect their gravitational signatures. Therefore, it is critical to mount a program of feasibility observations of the nearest SNe with the largest Earth-based optical telescopes.[19] If a number of such observations fail, then the observing will wait for a closer candidate,[20] a bigger telescope (such as the Thirty Meter Telescope), or both. In any case, SN 1986J, with 200 times the Crab nebula luminosity at 15 GHz, will be a collateral target in these observations. Keck 10-m time is available to Dr. Jerry Nelson, the Keck project scientist, and we would hope to make observations within the next two years, telescope scheduling being subject to several factors that are difficult to control. For targets in the Southern Hemisphere, SN 1987A is also a logical, collateral target, made a moon-bright, largest telescope target by the glowing of ejecta impacting

[18] The big one that remains, is, of course, the "how?" One approach involves superluminal polarization currents (see, e.g., Ardavan et al. 2004).

[19] It is likely that SN 1987A did produce optical pulsations as strong as 25 solar luminosities ($L_\odot$) 5.0 to 6.5 years of age (M00a,b).

[20] Or rather, a *better* candidate, i.e., an intrinsically fainter Ia with a high drop of velocity (gradient) wrt time, which is an indicator of a sufficiently low inclination to the merger axis (but not so low as to fall outside of the pulsar beam), so that there is a better chance of seeing past, rather than through, the high opacity Fe group elements.

the ER. Consistent detection of optical pulsations from SN 1987A with such telescopes could lead to a highly productive, long term monitoring program of this unique object, *which has not been observed with any instrument capable of detecting rapid pulsations for more than a decade, and has* ***never*** *been observed with any telescope of aperture >4 meters.* Whether one accepts the 2.14 ms candidate pulsar or not, these observations of SN 1987A *must* be made, and sooner rather than later, in part because they have the potential to impact Ia cosmology, and in part because the background from the equatorial ring will rise by a factor of 10 in the next decade, and by *another* factor of 10 in the following decade.

Since the Crab pulsar produces four $L_\odot$ in optical pulsations, SN 1986J might produce 800 $L_\odot$ in optical pulsations if these scale with the 15 GHz luminosity. With one of the Keck 10-m telescopes, the sensitivity to pulsed optical light under the best possible circumstances is near 500 $L_\odot$ at the 10 Mpc distance to the host galaxy, NGC 0891. However, we have no idea as to what the extinction was for 1987A during the four year span from 1992, Feb. to 1996, Feb., when it was more or less reliably detected. We only know that it faded by 1 – 2 mag after 6.5 years of age. The best earlier limit, at 1.5 years of age, was near 21.6 $L_\odot$ for the V + R + I band, characteristic of the Si photodiode (Pennypacker et al. 1989), but the extinction could have been very high this early.

Given all of the uncertainties, a 500 – 1,000 $L_\odot$ luminosity can not be ruled out for young remnants of merger SNe. This may mean that we likely only have a window of a few years when the most nearby Ia/c extragalactic SNe have any chance of being detected, even by the largest ground-based telescopes now available. Given the morphology of DD SNe, it is possible that, in Iac's, a line of sight may exist to the neutron star *in the first few weeks*, thus very early observations can not be ruled out.[21] Although it is unusual to request funding for observations which may well fail, if we don't do so, a window of opportunity to detect these sources could come and go without our having any knowledge of it.

It has been more than a decade since high time resolution observations have been made of *any* young SN, particularly none of SN 1987A (as mentioned above), due to various reasons, including Ia cosmology efforts at nearly all large telescopes on the planet. Partly as a consequence, the real problem we face is instrument commissioning at the largest telescopes, none of which have anything quite so (apparently) "useless" as a high speed photometer. The solution is a more versatile instrument developed by the Galway group, the TRIFFID 2-dimensional photometer, which consists of a beam splitter which divides the incoming light into two light paths, B and VRI, achieved with dichroic filters (Shearer et al.1997,8). The B beam is separately focused onto a L3 CCD Andor iXon DV887 detector (DQE ~ 50% in the B band), which has a 512 x 512 16 micron pixel field, thinned and back illuminated so it has >90% QE above 500 nm and >50% above 400 nm. The max readout speed is >=200 fps. The VRI beam is focused onto three avalanche photodiodes (APD; DQE's: R[70%]). Adjustments may have to be made for the higher counting rates expected because of the brighter ER of SN 1987A and larger telescope apertures. Dr. Andy Shearer is the PI for the instrumental effort, and we expect it to be ready to travel within a year. In 2009 TRIFFID will have the ability to measure polarization from stochastic and periodic events. Only Shearer's travel and shipping costs will impact this proposal.

[21] Two decades ago no one would have suggested that Ia's should be checked for optical pulsations at the nadir of their brilliance!

Within that period, we will initiate an observational campaign using Very Long Baseline Interferometry of the nearest recent Type Ia/c SNe. Observing at the largest baselines with maximum participating antenna, we will obtain images at 5, 8 and 15 GHz corresponding to a resolution of ~1 mas, or ~104 AU at 10 Mpc, sufficient to assess the visibility of a compact core, consistent with a compact object, as determined for SN 1986J (Bietenholz et al. 2004). Dr. Aaron Golden is the PI for the VLBI program, having used both the VLBA and EVN to determine pulsar parallax and resolve emission structures on radio active ultracool dwarfs. Only Golden's travel costs, under $5K/a will impact this proposal.

2.2.1 On Site Data Analysis

Computers have greatly improved over the past decade and a half. It would therefore make sense to install a suite of analyses into a portable/laptop computer. This may need an addon fast memory in order to perform very large Fast Fourier Transforms without thrashing the disk(s). A suite of programs written by former student Scott Ransom already exists, so it would make sense to use this, and modify it as needed. One desired algorithm would resample at a candidate's frequency including its suspected time of arrival (toa) modulation characteristic of some (but not all) forms of pulsar precession. Experience with candidate signals from SN 1987A near 2.14 ms has shown that the power recovered in the harmonic with a suspected toa modulation will be much less/more due to very narrow, intrinsic pulses/very large amplitude toa modulation (M00b). Middleditch will work with Shearer on the analysis suite, and we would expect this to be mostly ready within a year.

3. Calculations

The recent events in the nearby Universe have also rendered calculations of Type Ia SNe with the invalid paradigm, such as "gravitationally confined detonation" (Plewa et al. 2004) or "delayed Detonation" (Khokhlov 1991), into so much "computational science fiction." One of the goals of this proposal is to guide the calculations back toward reality, as this can not fail to benefit computational simulation efforts at the national labs. RAGE calculations may be useful for certain aspects of the beam/jet of SNe. Middleditch and a graduate student will work on the calculations which we expect to be substantially complete within a year.